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Visual Acuity Decrements Associated With Whole Body \pm Gz Vibration Stress

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The fact that vibration has an adverse effect on visual acuity is well established but inadequately quantified. The operational acceleration environments of low altitude terrain avoidance flight, the increasing use of helicopters, and the potential vibration problems associated with space flight launch and reentry all require a better understanding of visual performance under this stress. This study demonstrates that near, intermediate, and distant vision are differentially degraded under vibration stress. A method is presented to describe visual efficiency in terms of a Performance Index that should be useful to aeromedical scientists and clinicians, as well as design engineers.

would produce the greatest decrement. Visual targets or tasks used by previous investigators included Landolt rings,⁶ dial reading performance,^{1,8,9} numbers that were required to be read in limited time,² minimum vernier separation,^{3,6,7} as well as fixed targets with illumination varied.⁶ Obviously, it would be difficult to relate these to each other or to a meaningful Snellen acuity that is well understood by scientists of many disciplines. In addition to this difficulty, the differences in previous techniques suggest that the visual degradation

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IN RECENT YEARS a number of papers have been published dealing with visual performance as a function of vibration stress. Considerable disagreement exists within these reports as to the extent of visual loss as well as the particular frequency bands which

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may be a function of viewing distance.

This report deals with the development of a technique to quantify data concerning visual performance during exposure to whole body Z-axis sinusoidal vibration. As more complex, multiaxial motion simulators become operational, a systematic investigation of the effects of complex flight environments on visual performance can be accomplished. By developing a Performance Index for visual acuity, it will be possible to provide designers with directive data on limitations and possible enhancements in the vibration-acceleration environment.

METHOD

The vibration stress selected for this investigation consisted of incrementally varied frequencies of 5 to 50 Hz at ± 0.75 Gz and from 10 to 50 Hz at ± 1.50 Gz. Because of the possibility of approaching human tolerance limits,^{4,10} frequencies below 10 Hz were not tested at ± 1.50 Gz. The vibration was applied to seated human subjects while monocular visual acuity was determined at three test distances. These distances: 40 cm, 1 M, and 4 M represent respectively, near or reading, cockpit layout or instrument panel, and far or outside environment visual tasks.

Fifteen subjects were selected from a panel of human volunteers from the Vibration and Impact Branch of AMRL. All were medically qualified and had passed a Class III flight physical within the past year and had Snellen V.A. of 20/20 or better in each eye with suitable refractive correction.

The subject was seated in the MB Electronics C-5 Vibration Test Unit shake table without cushion or footrest. His torso was restrained in the aircraft type seat by lap belt and shoulder harness. The head was

not restrained in keeping with the operational nature of the investigation. The visual target was fixed in space directly before the subject, at the appropriate distance. Thus, any movement in the target-subject relationship was a function of subject movement alone.

Near Vision—A Jaeger near point card was placed directly in front of the subject at a distance of 40 cm and was well illuminated by a high intensity surgical floodlamp.

Monocular acuity was determined at each of the vibration settings described above, as well as at a no-vibration control setting. A random order of vibration settings was selected by the technician who reported the specific vibration parameter following the test. This "double-blind" experimental format was utilized in order to minimize the errors of anticipation in both subject and experimenter. Snellen visual acuity was measured and recorded at each point of the experimental spectrum.

Intermediate Vision—The procedure was identical except that test distance was one meter while the target was a standard Snellen chart, photographically reduced for use at this distance.

Distant Vision—This procedure was also the same except for target and test distance. An American Optical Co. Project-O-Chart projected a series of "illiterate E" symbols to a screen 4 meters from the subject. Target size was adjusted for the 4 meter distance.

Data Reduction—The means and standard deviations of the Snellen denominator were determined by computer for each vibration mode and test distance. In addition to this, each subject's acuity in each mode was converted to a Performance Index (P.I.) by dividing his "control" Snellen acuity by his "experimental" Snellen acuity. For example, if Snellen acuity was 20/15 in the control (non-vibrating) mode and 20/30 in a specific vibration mode, the P.I. would be:

$$\text{P.I.} = \frac{\text{control}}{\text{experimental}} = \frac{20/15}{20/30} = \frac{15}{30} = \frac{1}{2} = 0.50$$

There is certainly no substantial difference in the two methods of data presentation, however, the use of the P.I. has an advantage. By using each subject as his own "control" rather than comparing "group" data to "group" control, it permits the direct evaluation of any efficiency criterion directly from a graph or table.

RESULTS

Tables of the data, showing means and standard deviations of visual acuity and of performance index, were prepared for each vibration mode for each test distance. The data are presented graphically with visual acuity or P.I. on the ordinate and the vibration frequency and displacement on the abscissa.

Near Vision—A visual loss was demonstrated for each of the vibration modes when compared to control performance. The loss seems to be directly related to the displacement or amplitude of the vibration since the curves of both acuity and of P.I. are essentially quite smooth and seem to be asymptotic to control

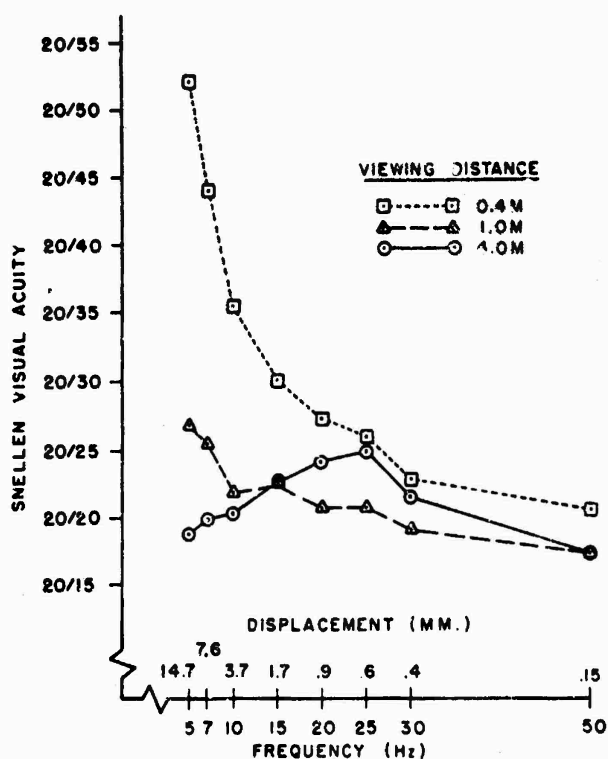


Fig. 1. Snellen visual acuity at ± 0.75 Gz as a function of frequency (or displacement) and viewing distance.

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levels as the frequency increases. For each frequency, the effect was greater at ± 1.50 Gz than at ± 0.75 Gz, and grossly proportional to the amplitude. The curves show a slight departure from complete continuity in the 20-25 Hz range. Although this might be dismissed as an experimental artifact, it may well be related to a failure of the tracking reflex at this frequency. (See Discussion)

Intermediate Vision—The results were essentially similar to those obtained in the first phase, except that at the middle and low frequencies, the visual losses were less. If we assume that the major factor in any performance decrement is the linear displacement of the target-subject geometry, this would not be surprising.

Distinct Vision—The data and curves generated in this phase were quite different from those of the first two. While visual performance at the closer distances decreased in an almost linear fashion as vibration frequency decreased, the decrement at four meters was greatest in the 20-25 Hz range. Performance at both extremes of the test spectrum approached that of the control level.

DISCUSSION

The prime purpose of this initial study was to determine a means to quantify the visual decrement that accompanies moderate sinusoidal vibration. This has been accomplished as well as the discovery of the importance of test distance.

For near and intermediate test distances the angular displacement in the subject-target relationship seems to be the dominant factor in predicting visual loss. A similar effect is noted at the 4 M distance but only at frequencies greater than 25 Hz. The visual loss is

grossly proportional to the amplitude of the vibration.

As the test distance increases the linear displacement created by the vibration becomes a smaller angular displacement and should merely result in a reduction of the visual loss. First inspection of the curves generated at distance does not bear out this hypothesis.

Consider that the tracking mechanism of the eye is capable of maintaining fixation on the oscillating (relative to the eye) target, provided that the movement is predictable and that the changes in direction are small and occur at a low frequency. As an example, if the angular velocity were only 1 degree per second and the

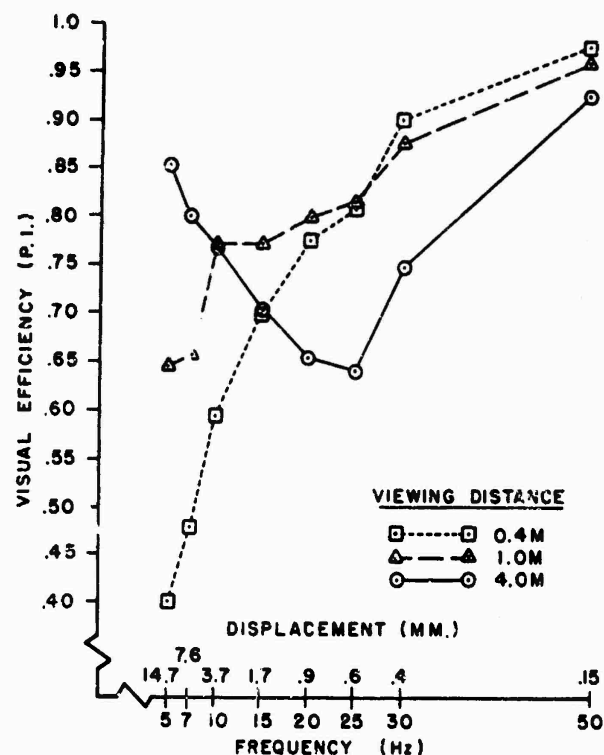


Fig. 3. Visual efficiency at ± 0.75 Gz as a function of frequency (or displacement) and viewing distance.

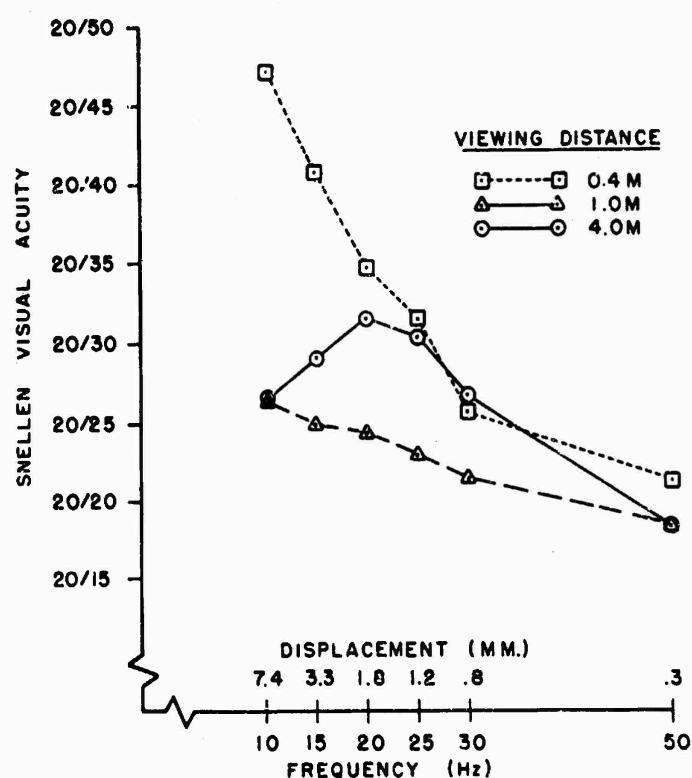


Fig. 2. Snellen visual acuity at ± 1.50 Gz as a function of frequency (or displacement) and viewing distance.

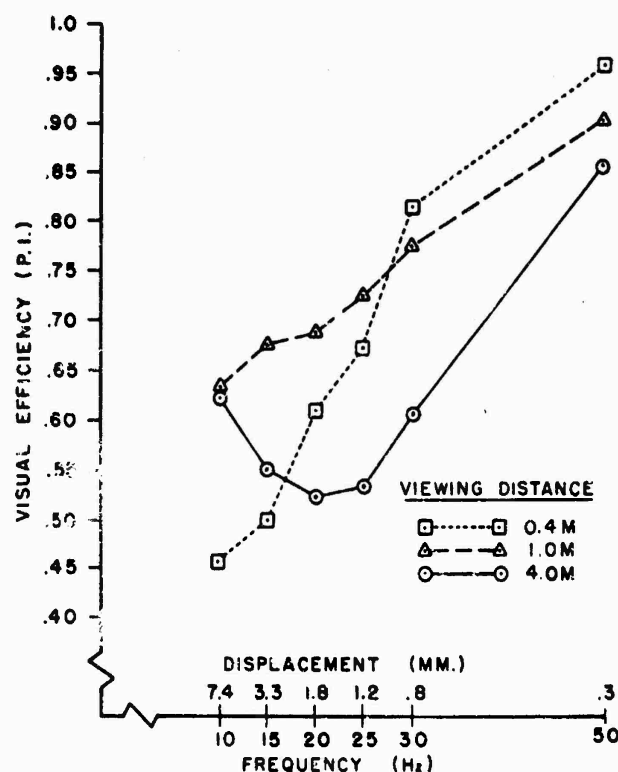


Fig. 4. Visual efficiency at ± 1.50 Gz as a function of frequency (or displacement) and viewing distance.

total displacement only 1 degree, this movement could be followed perfectly. As these two factors, angular velocity and frequency, increase, a point would be reached at which the tracking mechanism would no longer function adequately and there would be a decrement in visual acuity. Although previous reports indicate that the tracking reflex probably follows sinusoidal movement only to about 2 or 3 Hz,² it is entirely possible that the mechanism could function beyond this rate (as long as the oscillations were perfectly predictable) by following alternate changes in direction only. This could be carried further, of course, to allow only every third or fourth oscillation to be "tracked." Although this would not result in perfect performance as when tracking occurred in the 1:1 mode, it would still produce better acuity than in a completely passive, nontracking mode of visual observation.

At close range, the angular amplitude of the target-observer relationship is large and cannot be effectively "tracked." As the distance is extended, although the frequency and linear amplitude are unchanged, the relative amplitude and angular velocity of the subject-target relationship are decreased, permitting at least partial tracking to take place.

At high frequencies (above 20 or 25 Hz), the eye cannot "track" the moving retinal image, and so the visual loss is proportional to the angular amplitude of the moving retinal image. At near distances the angular amplitude is too great for tracking to occur, so that the same principle applies to the extent of the visual loss. However, at greater distances, if the frequency is below 20 Hz, some degree of tracking may occur, so that at 5 Hz vision is only slightly affected, becoming worse towards 20 Hz where all attempts at tracking cease. Beyond this frequency the amplitude is relatively low so that although there is no tracking, the performance degradation follows the pattern established at near, but, of course, reduced in effect because of the reduced angular amplitude.

This hypothesis can account for the differences in the performance at near and distance and will be the object of further investigations.

SUMMARY AND CONCLUSION

A method has been developed to determine visual acuity under vibration and to express this data in a visual efficiency transformation; the Performance Index. Additionally, it was shown that consideration of target distance was essential when evaluating visual performance. This study presents three distances which operationally represent: (1) reading (maps, checklists, etc.); (2) controls and displays (cockpit layout, instrument panel); and (3) distant vision (outside the cockpit, air

to air, air to ground).

A different curve of performance index was obtained for each of these three distances, thereby providing a method to consider visual performance in relation to the requirements of an entire mission profile. For example, certain vibration levels might be acceptable if only distant vision is required, but would be detrimental in terms of reading or near vision performance.

Furthermore, by expressing visual acuity as a Performance Index, it should be possible to make certain trade-offs. For example, a certain display might require maximum visual efficiency ($PI = 1.00$) to critically monitor with zero error, while a second display could be effectively monitored at a $PI < 1.00$, but would compensate for the adverse vision effects of the vibration-acceleration environment.

Finally, a visual performance index presents data in a form that is useful, not only to aeromedical scientists, but to clinicians and engineers as well.

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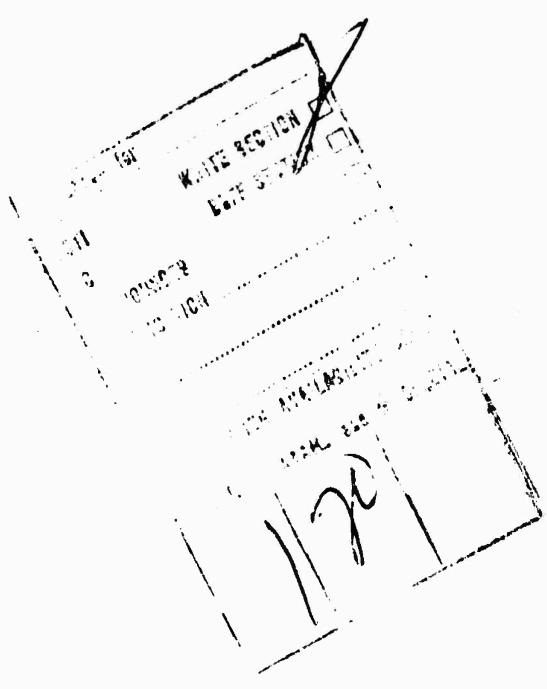
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